narrow and decompound state of *D. ligulata*, as it occurs on the British coast, to that of the Alga under consideration, is very remarkable; and as far as I know, intermediate states have not occurred. But Professor J. Agardh speaks of the frond of some French specimens of *D. ligulata* as an inch in breadth. Professor J. Agardh's var. β. (*D. herbacea*, Lamx.) and var. γ. (*Sporochnus herbaceus*, var. *firma*, Ag. Syst.) do not at all agree in their pinnated forms and spinuloso-serrate margin with our plant; and if his conjecture should eventually prove to be correct, it would be difficult to adduce a more extraordinary deviation from a specific type. It might be described as var. δ. *subsimplex*. In the mean time a figure (Pl. XIV. fig. 1) of so interesting an Alga will, it is hoped, be not unacceptable to the British botanist.

XXVIII.—*On the Mechanism of Aquatic Respiration and on the Structure of the Organs of Breathing in Invertebrate Animals.*

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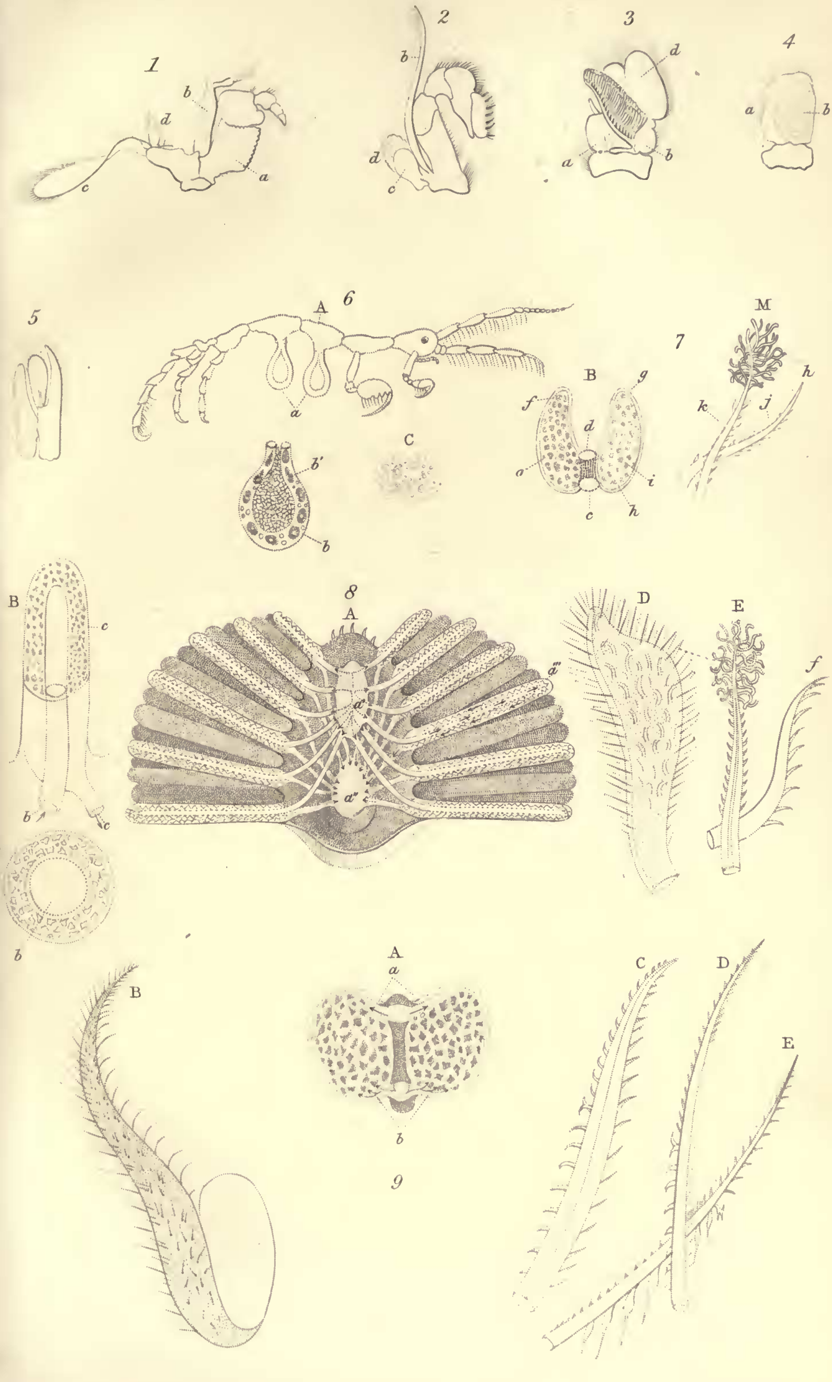
[With two Plates.]

[Continued from p. 200.]

The epidermal skeleton of the Arthropoda is histologically peculiar. *Chitine* was first defined by Odier*. In the year 1845 it was more fully investigated by C. Schmidt†. By Lassaigne it has been distinguished under the name of *Endomaderm*: it is a proximate principle which resembles *cellulose*. Both are insoluble in caustic potass. Nitrogen however is present in chitine and absent in cellulose: it is the animal basis of the integumentary structures of Insects and Crustacea. It is a principle of low vital properties. To the presence of this substance is probably to be ascribed the fact, already mentioned as extraordinary, of the universal absence of vibratile cilia from *all* the structures of Insects and Crustacea. And why is *vibratility* not a property of those organized parts of which *chitine* is the proximate basis? The very definedness of this question marks an advance in the real *science* of physiology. Effect is linked to its true cause, attribute to its right substratum, function to its immediate instrument. Chitine is produced under two distinct conditions: in Insects it occurs under the circumstances of atmospheric respiration, in Crustacea under those of the aquatic.

* Mém. de la Soc. d'Hist. Nat. de Paris, 1823, p. 29.

† Zur Vergleich. Physiol. d. Wirbellos. Thiere, p. 32.



T. Williams, del. ad nat.

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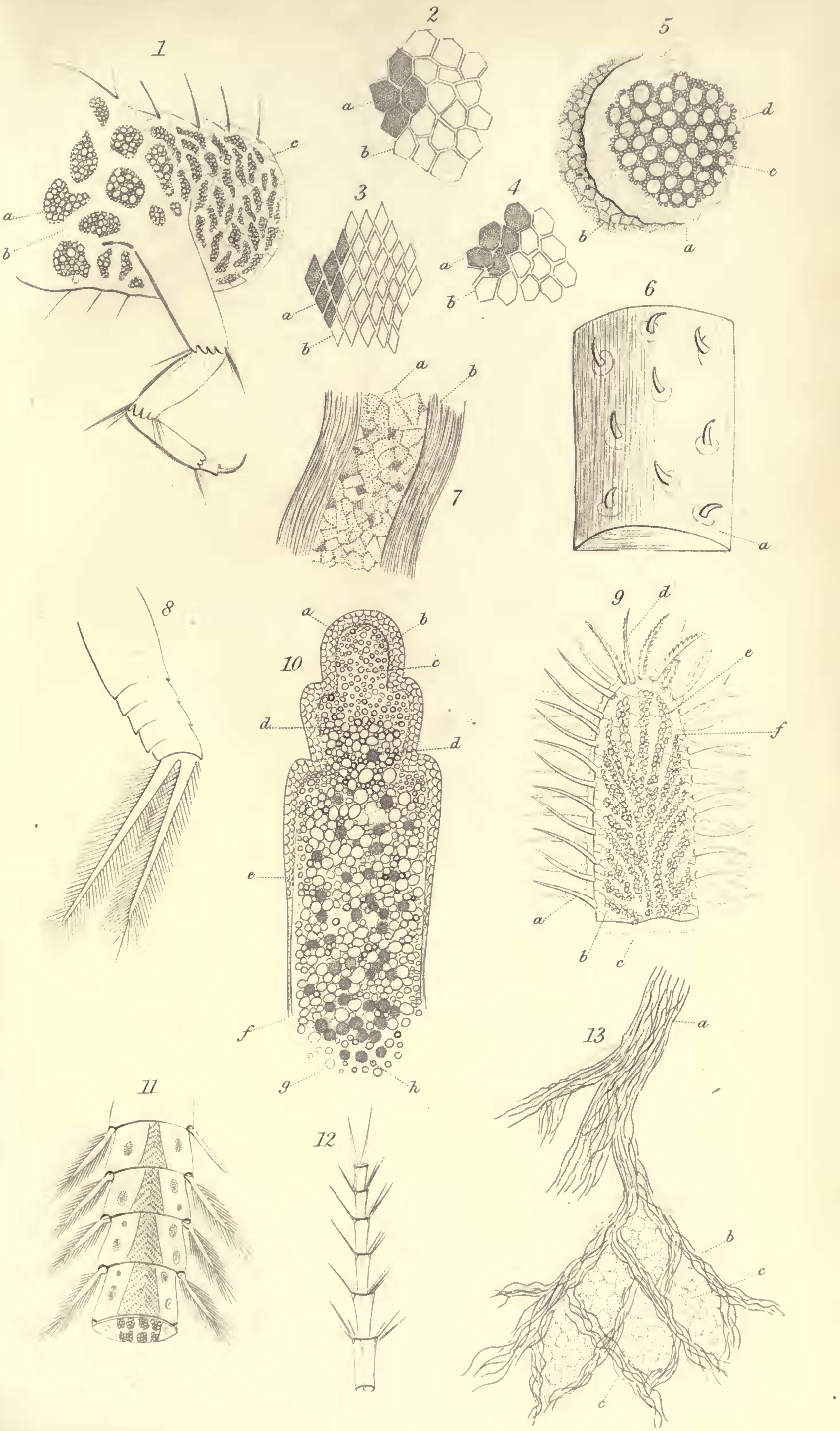
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The *external* machinery of the process of breathing, however unlike the constituent parts, or different the principle of its action, does not therefore appear to involve any difference in the ultimate products of the nutritive actions of the organism.

The suppression of motive cilia in the Arthropoda is the signal of the saving of power. The economized force is diverted to other purposes. The nervous and vascular centres are raised in standard: the whole muscle-system is augmentedly developed, and the secernent organs are woven into more complex structures. The presence of chitine in the dermal skeleton of the Articulata entails a distinctive character upon the periphery of the circulatory system. Contractile vessels cannot exist in the substance of an incontractile solid. This segment of the circulation of Insects should be studied with special reference to this point. When the skeleton is very thick, it is composed of a series of superimposed laminæ, between which are tunnelled certain channels, as in bone, for the conveyance of the nutritive fluid. In the centre of the larger of these channels tracheæ may be demonstrated*.

The true epidermis of Insects is always and universally composed of a tessellated hexagonally-celled epithelium. The anatomical characters of the ultimate blood-channels of Insects will be most successfully studied in the corresponding parts of the circulatory apparatus of the Crustacea. The same description essentially applies to both.

Crustacea.

Every Crustacean is a water-breathing, every Insect an air-breathing animal. To this rule there can be found no real, many apparent, exceptions. In the system of the Crustacean there exist no *water* tracheæ. Although the Crustacean is an insect breathing water, the mechanism contrived to accomplish the process is comparable in no single particular with that used in the instance of the Insect breathing air. In the former plan there is no wonder-striking singularity. The apparatus employed is common to every aquatic animal. The organs of breathing in every true crustacean conform essentially to the aquatic type. Though some species seem to enjoy the power of respiring on the atmospheric plan, the apparatus used fulfils the requirements of the branchial principle.

One typal form of blood-corpuscle prevails throughout all the species of this class. The fluid, in the embryonic state, as in the larvæ of Insects, and antecedently to the evolution of the branchiæ and the heart, presents a description of corpuscle different from that which afterwards in the same animal charac-

* See Histological Catalogue by Prof. Quekett.

terizes the adult fluid. The former is a real chylaqueous compound, is moved by means of the general muscles of the body, and undergoes the change of aëration without the intervention of any special organs.

Central parts of the Circulatory System.

In this class *the heart* occurs under the character either of a saccular vesiculiform viscus, or under that of the vasiform or tubular.

In the higher species, in which the organ is partly branchial and partly systemic, it is the point of departure of an arterial system of distinctly walled pulsatile tubes which in the lower becomes abortive. It is placed in the axis of the body, directly under the shell, at the anterior part of the back, and is often attached to the internal surface of the dermal skeleton by muscular fibres: it is the chief propelling power of the blood. In the Siphonostoma and Lophyropoda it is a simple sac, either spheroidal or elongated in figure: it has only two orifices, a venous behind and an arterial in front. This organ in the Decapods, occupying the middle of the cephalothorax and star-shaped, passes off into arteries in front, behind and below, the returning venous blood entering through orifices at the upper and lateral portions. In the Pœcilopoda, Isopoda, Amphipoda and Læmodipoda it is tubular in form, and occupies the mid-region of the dorsum, sends off arteries before, behind and laterally, and receives the venous blood through lateral venous orifices. It is most highly developed in the Stomapoda. In the Phyllopoda it approaches the Myriapodal chambered type.

In the lower Crustacea the blood passes from the heart directly into intervisceral lacunæ: no defined vessels exist. In the higher, in which the organ is unarticulated and more centralized, arterial trunks occur; after a short course they are lost in the interstices of the tissues.

The *venous currents* converge from the lower part of the body into various intercommunicating sinuses, situated some upon the median line and others at the base of the appendages. From these sinuses the blood proceeds to the branchiæ and thence into the dorsal sinus, the walls of which are thin and non-contractile, and within which the heart is entirely enclosed.

This dorsal sinus is filled during the systole, and the arterialized blood which it contains is absorbed during the diastole through the venous orifices of the heart without any aid on the part of the walls of the sinus *.

* See Anatomy of the Invertebrata, by Siebold, translated by Burnett, for very copious bibliographic references on the literature of this and all other classes of Invertebrated animals.

General descriptive Anatomy of the Branchial Organs.

The ultimate questions of structures will be more advantageously studied if preceded by a few general statements as to the more prominent characters of the organs dedicated to the office of respiration. The Siphonostoma, Lophyropoda, and many Stomapoda present no special branchial organs.

Those of the Læmodipoda and some Stomapoda are reduced to a few vesicular or cylindrical, sometimes wholly rudimentary appendages which hang freely from the base of some of the feet, or are inserted isolatedly at the sides of the body (Pl. XVIII. fig. 1). The Phyllopoda are provided at the base of each of their swimming feet with an ovoid or lanceolate branchial lamella: it is distinguished from the feet by the absence of bristles.

It is only the first and last pairs of feet in the Amphipoda which are modified into respiratory organs.

In the Isopoda the five pairs of post-abdominal feet are nearly always concerned exclusively in the office of breathing. The two multi-articulate cirri of each of these feet are changed into plates (Pl. XVII. figs. 4 & 5), which directed backwards, are imbricatedly arranged and applied against the under surface of the last caudal segment. In shape these plates differ according to the species. Intermediate between the Isopoda and Decapoda, the Pœcilopoda in their branchial organs partake of the characteristics of both. Inserted on the abdominal feet they resemble those of the first order; lamellar in figure they approach the branchiæ of the Decapods.

The respiratory organs of some Stomapoda (Pl. XVII. fig. 3) are evolved in the highest degree; they consist of tubular tufts arranged around a stalk, and float freely in the external medium. In anatomical structure they fall under the type of those of the Lobster (fig. 8). In *Squilla* these tufts exist on the ten anterior feet.

The branchiæ of the Decapods are attached to the bases of the anterior abdominal feet, lodged in a branchial chamber, and protected by the cephalothorax. The most developed form of the breathing apparatus in the Crustaceans occurs in the Decapods. In this order not only is the function thrown upon particular organs entirely set apart for the purpose, but these organs are lodged and protected within a special cavity; and the renewal of the water necessary to their operation is secured by the motion of distinct appendages or *flabellæ*. The thoracic cavity is formed by a reduplication of the external tegument, and is provided with two orifices, one for the introduction and the other for the expulsion of the fluid. Through these orifices a constantly renewed supply of water is made to pass by the agency of a large valve-like organ, placed in the efferent canal, which by its movements drives a continual current from behind forwards, or from within outwards, and thus occasions a constant ingress through the afferent opening: this organ is the flabellum. It is the modified appendage of the second pair of feet-jaws, specially developed to answer this purpose. The perfect contact of the water with the respiratory surface is further ensured by the actions of the flabelliform appendages of the other maxillary or ambulatory member, which in most Decapods penetrate into the branchial cavity, and incessantly sweep and comb over the surface of the branchiæ. The membrane lining the branchial chamber in some land Crabs, which not only habitually live out of water, but are infallibly drowned if immersed in that fluid, is sometimes disposed in folds capable of acting as reservoirs for a considerable quantity of water, and sometimes presents a spongy texture equally well adapted for storing up the fluid which is necessary to keep the organs of respiration in the state of humidity required for the performance of their functions*.

The preceding cursory account is offered only as an introduction to that narrative of original details which is now to follow.

An exact inquiry into the circumferential circulation of the Crustacea will serve to elucidate the apparatus of the blood-system as it exists in the Insect organism. It is only by a minute scrutiny into the last extreme of the blood-current, that the physiologist can penetrate the mystery of the nutrimental act and the ultimate mechanism of the respiratory process. No opportunity is more favourable than that offered in the example of the Crustacea;—the structures are transparent; the blood-current is obvious to the eye; every element of structure may be readily reduced to its last analysis.

Minute Anatomy of the Peripheral Blood-channels and Branchial Organs.

In nearly all species the *primary* blood-channels, both venous and arterial, are circumscribed by a special membrane which is a distinct and separable structure. The arterial trunks are contractile; they embrace closely the contained fluid. The muscle-tissue present in the parietes of the heart extends evidently to those of the arteries. The veins are non-contractile; their walls adhere externally to the solid parts, amid which they lie; they cannot therefore contract in transverse diameter; they are passive conduits, the arterial are active. The arterial and venous trunks are lined internally by an extremely fine hexagonally-celled epithelium (Pl. XVIII. figs. 2, 3, 4). The cells present re-

* See Carpenter's Principles of Comparative Physiology.

markable regularity in size and outline. They are not detectable on the internal walls of the parenchymatous passages which coincide with the capillary segment. The blood-channels are *therefore* here imparietal. The epithelium ceases where the special boundary of the artery ceases; it begins again at the limit denoting the origin of the true veins. This hexagonally-celled epithelium is the prevailing envelope or lining of all organs and cavities in the Crustacea. It betrays no other diversities than those which depend upon the size and distinctness of the contained cell-granules. The cells are *never* furnished with a nucleus. The granules are in the interior of the cells, and adhere internally to the cell-wall. A different opinion is expressed however by Professor Quekett: he describes the granules as belonging to the underlying structures. The error of this description may be placed beyond doubt by the reagency of acetic acid. Dr. Carpenter denies the existence of cells in the epidermis. In the adult Crab, for some time after the moulting has taken place, that is, after the shell has become hard, it is, as this author states, impossible to detect the cellular arrangement of the membrane exterior to the calcareous layer. The cells seem to have been mechanically worn away. Soon after the moulting however, the presence of *cells* in the epidermis of the carapace, for instance, admits of easy demonstration.

The hexagonally-celled epithelium is an element of varied use and great importance in the crustacean organism; it constitutes real boundaries everywhere of the extreme or capillary circulation (Pl. XVIII. fig. 5). Plates (*a, b*) are formed by the apposition of its constituent cells laid accurately edge to edge: these plates are united by interposed islets or patches of parenchyma (Pl. XVIII. fig. 1, *a*). Between the latter are left large, irregularly and angularly bounded passages, traversed by the extreme blood-currents (fig. 1, *b*). The islets of parenchyma consist of a variable number of nucleated cells, filled obviously with the *fluid* elements of the blood. The groups differ in size and outline in different organs. They are sometimes embraced by a common capsule: in such a case the latter would constitute the real boundary of the blood-channel. As such a capsule is the independent envelope of a detached group of cells, rather than the continuous boundary of a conduit, however irregular in form and outline, it cannot with any anatomical propriety be defined as the *wall* of the latter. The epidermal plates, between which the blood-passages are disposed, are inflexible, firm, non-contractile. "Membranous parietes" of blood-vessels adherent internally to these plates could not contract upon the contained fluid without approximating the plates. Such an effect would imply a strong muscular effort. No muscles exist in these extreme situations. No separate vascular membranes bound the peripheric blood-currents; therefore no "*capillaries*" exist in the Crustacea. The fact then is now susceptible of general expression, that in the articulated animals, most certainly in Insects and Crustacea, the *peripheral circulation* in consequence of the presence of a firm unbending epidermal skeleton, cannnot by mechanical possibility be any other than it is, namely a profusion of irregularly subdivided streams, traversing angularly bounded passages in fixed non-contractile inflexible solids. An exception to this axiom may exist in the example of some of the internal organs—probably in the musculo-glandular walls of the alimentary canal, certainly not in the liver of the Crustacea, as will be afterwards shown.

Let now these general anatomical facts be applied to the analysis of the branchial organs in their several varieties in this class, or to the mechanism of the respiratory act, where there exists to this end no separate provision.

The *araneiform* Crustaceans are furnished with no separate respiratory organs. Almost every English systematic writer describes the Pycnogonidæ as destitute of a true circulating system*. This is an error. In *Pycnogonum* the existence of a dorsal vessel lying on the dorsal aspect of the stomach may be readily demonstrated. The blood follows the cæcal diverticula of the stomach into the legs; it returns by separate channels along the ventral aspect of the cæca into an auricular division of the heart. The peripheral blood-currents do not subdivide. The solids are not permeated by subdivided capillary currents. Everything beyond the main stream is *cyclosis*—that is, *non-corpuscular* fluid passes by endosmose from cell to cell. This extra-vascular movement of fluid plays a part in the nutrition of the solid structures of Invertebrata, of which the frequency and the extent are by no means yet rightly estimated by the physiologist. The floating corpuscles of the blood never pass beyond the walls of the proper vessels: they never reappear *de novo* in the fluid beyond the vessels. In the latter region the fixed cells impress upon the blood required changes. But this extra-vascular fluid *after leaving the vessel,* may unquestionably undergo the process of aëration. This is exemplified in the Pycnogonidæ, in which the blood-current is so little subdivided. In this group the floating corpuscles are relatively to the size of the animal very large. They conform to the crustacean type; they are granular and nucleated, suspended in a clear, colourless fluid. They move in

* "In one of the most degraded forms of the class, we revert to the simplest possible type of the circulating apparatus; even the dorsal vessel, which is so characteristic of the Articulata, being apparently deficient in the Pycnogonidæ."—Dr. Carpenter's Principles, &c., p. 695.

a definite orbit. This fact alone proves the presence of a heart —if the fluid constituted a chylaqueous system its movements would be oscillatory.

The Entomostracous Crustacea present few diversities as regards the number and disposition of the parts dedicated to the office of breathing. In every species the feet are found to be modified parts. The circulating system is crustacean, not insect-like, in type. The dorsal vessel is a simple tube; it is in no instance moniliform; it is *not* multiplied by valves into independent contractile chambers. The peripheral circulation is *lacunar*, not capillary*. In the Branchiopodidæ the articulations of the feet expand foliaceously. An augmented surface is thus created. It is utilized respiratorily. By the ceaseless action of the legs a current in the surrounding element is maintained, which is applied to the purposes of respiration. In every order of Entomostracous Crustacea the extreme circulation coincides precisely in every particular with that afterwards to be described in the higher Crustacea. Every appendage of the body is subservient to the function of breathing.

In the families Nebaliadæ and Branchiopodidæ, the abdominal appendages of which are foliaceous, currents of blood can be traced by aid of the corpuscles, traversing irregular passages which coincide with great exactness with those so easily seen in the corresponding appendages of the Macrourous Decapods.

In several genera of the familiar Daphniadæ, and Lynceidæ, the extreme blood-currents in almost every part of the body can be clearly defined by the eye. In every foot, in every foliaceous appendage, in the very bristles, the act of aëration is accomplished. The blood-corpuscles in all Entomostraca are crustacean in type and structure. They are small in number relatively to the bulk of the blood.

In *Caprella linearis* (Pl. XVII. fig. 6), a filiform crustacean, common in the Bay of Swansea, two membranous processes (a) depend from the under surface of the abdomen. By Milne-Edwards they are said to be vesicular. They are really flat. A *single* current of blood courses round the circumference ($b' \, b$). The centre of the lamina is parenchymatous. These organs exemplify a principle in the organization of the Crustacea. They prove how little is the measure of the respiratory function in the Crustacea, compared with the high nervous development and active muscularity of these animals.

* The general facts stated in the text may be verified most readily by the examination of any of the numerous Entomostraca which inhabit our freshwater pools. Microscopic in size, they admit of being easily submitted to inspection.

No setæ or bristles of any description are added to these simple organs. They are enveloped in an exquisitely-attenuated tessellated epithelium. It preserves its tenuity without a sacrifice of stiffness. These organs are very readily converted into *vesicles* by compressing the body of the animal. The force of the fluids separates the parallel laminæ, and converts a plane into a sac. They are moved by muscles at the base; they are attached to the second and third segments of the thorax. The action of the water upon them is auxiliated by flabellæ. They exhibit the apparatus of breathing under the characters of the greatest simplicity.

The common *Talitrus* will serve to illustrate the anatomy of the branchial parts in the Amphipodan family. The thoracic limbs are commonly said to be transformed into branchiæ at their bases. The depending edges of the dorsal plates (the epimeral pieces of the tergal arc) are however much more suitably organized than the proximal articulations of the legs (Pl. XVIII. fig. 1, *c*). They are penetrated by a very dense system of canals (*b*, *c*). The epidermis is reduced to an extremely thin and transparent lamina. The component hexagonal cells may be readily observed (fig. 2). The outer or epidermal lamina is united to the opposite parallel lamina by dots of parenchyma (*a*). The blood streams in the intermediate passages (*b*). These parts therefore correspond in ultimate structure in the most exact manner with leaves of the branchiæ of the Crab. The bases of the legs are filled with muscle fasciculi. In *Talitrus*, as in all Crustacea, the blood-currents are large and few in number. No setæ or bristles of any sort belong to these lateral branchial plates. The respiratory current is maintained by the action, which is ceaseless, of the three pairs of abdominal prolegs. In several orders of this family the flabellæ of the abdominal appendages are converted into branchiæ (Pl. XVII. figs. 4 & 5). In minute structure they coincide with the lateral respiratory plates of *Talitrus*. From these parts, when thus specialized for breathing, bristles are absent. The associated *palp* excites the aërating current.

In the family of Stomapoda, the species of which are rarely found in the British seas, each segment of the abdomen is furnished with a pair of broad natatory feet, the basilar joint being quadrilateral (Pl. XVII. fig. 3, *a*), each bearing two lamellar branches (*d*), the exterior of which gives attachment on its posterior face, and close to the peduncle, to a *tufted branchia* (*b*). The minute structure of the branchial tubuli conforms in every respect with those of the Lobster, afterwards to be described. Each tubule is traversed in its centre by an afferent column of blood, which breaks out into a network along the circumference on its return to the proximal extremity. They are admirably fitted for the intended purpose.

The respiratory organs in the *Decapod* Crustaceans manifest the highest specialization. They are fixed to the sides of the thorax, and lodged artfully in expressly provided thoracic chambers.

Two types of structure prevail among this class, the tubular or cylindrical, and the laminar. Both forms are exemplified in the Macrourous decapods. The tubular is less common than the laminar. *Scyllarus, Palinurus, Gebia,* and *Homarus* are genera which afford examples of the cylindrical or tubular; in *Astacus* the tubules of the branchiæ are less numerous, and are disposed only on two of the sides of the branchial shaft, having a pinnate appearance; those tubules which are inserted on the coxæ are terminated by a thin, multiplicate, lamelliform dilatation, and resemble in structure an ordinary branchial lamella.

The coxæ in *Homarus* and *Palinurus* are provided with a plate-like process inserted at the side of the coxal branchia. It is of a leathery consistence, and covered with numerous hairs. The presence of these bristles proves that it cannot participate in the process of respiration. It is probably only a septum of separation between the branchiæ. In *Aristeus,* in which the branchiæ are sixteen in number on either side, they are penniform. They are composed of a shaft, from which pass off right and left numerous curled filaments, whose convex borders are covered by tufts of very delicate, densely packed, branchial cylinders.

The second or *lamellar type* of branchia occurs in all the Brachyura and Anomura, and in the genus *Galathea* among the Macroura. This type prevails also in the genera *Palæmon, Hippolyte, Alphæus, Penæus, Crangon**.

The familiar Lobster affords the best example of the first or cylindrical type of branchiæ. They consist of plumose pyramidal processes, enclosed in a thoracic cavity, and provided with peculiar *flabellæ.* The latter subserve the twofold use of agitating the water and cleansing, and separating the minute tubercles of which the organs are composed. In number the branchiæ vary in different species. They amount to 20 in *Astacus,* and in the most nearly allied species. In other Macroura the number falls. In the *Palinuri, Scyllari* and *Penæus* it is 18; in *Pandalus,* 12; in the *Calianassæ,* 10; in the *Palæmons,* 8; 7 only in the *Crangons, Hippolytes,* and *Sergestes.* In the Lobster, the Crawfish, in *Nethrops, Palinurus,* and the *Scuyllarus,* the branchiæ are subdivided most elaborately into minute tubular

* Ann. d. Sc. Nat. xi. 1827, pl. 26, and xi. 1839, pl. 3. fig. 1, pl. 4. figs. 1–4.

or cylindrical processes, which diverge at right angles from the axis of support, in which the main afferent and efferent channels of the blood are lodged. The gill of the Lobster (Pl. XVII. fig. 8) expresses, typically, the general and minute structure of the branchial organs of *all* the above-enumerated genera. They consist of fourteen separate organs, disposed in two alternate series, and lodged in a thoracic cavity. Each gill, conical in general figure, resolves itself into a multitude of small tubes (fig. 8, a'''), proceeding from the sides of the axis. In a transverse section, it will be seen that the large afferent trunk (a), running up one side of the axis of the whole gill, sends off a minute branch to *each* lateral tubule (a'''). A single tubule (B) has then its afferent vessel, which runs along its central axis (B, b). The sides of this afferent vessel are cribriform, so that the blood readily escapes at *every* point of its course into the loose lacunose tissue (C) and (B, c) which forms the *circumference* of the tubule, and through which the blood returns to the efferent or venous trunk (B, c). The blood-corpuscle thus runs round the circumference of a cylinder. This latter represents the area and period of aëration. It corresponds with a plane surface equal in length to such circumference. There is not, therefore, either functionally or structurally, any real difference between the cylindrical branchial filament and the leafy variety of this organ. The walls of the tubule are perfectly smooth. The hexagonal cells of the epidermis are detectable at the extreme outermost coat. These cells differ from those of the ordinary epidermis in nothing but in the fact of their greater tenuity. The islets of the included parenchyma are composed of nucleated cells. They are nourished by the branchial blood. The presence of these masses of living solids in the midst of the blood-current, at the very point at which the latter is undergoing aëration, concludes the controversy as to the capacity of the fluid in such place and time, at one and the same period to receive oxygen and to nourish the parenchymatous tissue. Here it is accomplished. The question *why*, in the Lobster and its kindred, nature should resort to this curious method of multiplying and subdividing the branchiæ, illustrates the unsearchableness of ultimate causes.

In the Lobster, as in the Crab, two orders of *flabellæ* exist. The first consists of a whip-like process, moved by powerful muscles, and guarding the *out*let of the branchial chamber (Pl. XVIII. fig. 9. shows the minute structure of extreme end). By its regular movements, a determinate current of water flows outward. The edges and flat surfaces of this marvellous instrument are profusely armed with secondary instruments (Pl. XVIII. fig. 9), matchless for their beauty, surprising as means to an intended end. The external or horizontal *flabellum* is sufficiently long to sweep vertically over the whole group of gills. From its position and structure, it can affect only the outermost surfaces of these organs. If this instrument were a simple, flat, smooth-edged process, it is easy to conceive, that during its motion over the branchiæ from above downwards, the component tubuli of the latter could not by mechanical possibility be separated so as to favour the rush between them of the aërating element. This difficult purpose is accomplished by an inimitable contrivance. The flabellum is covered in rich profusion with minute, flexible, mop-like threads (fig. 8, E). At the distal extremity of each seta or bristle, a group of minute flexible processes are added. A structure of so great singularity cannot be misinterpreted. The purpose which they are designed to fulfil cannot be mistaken. They constitute artfully-adapted provisions for cleansing, mopping, separating, agitating the constituent filaments of the branchiæ. No other description of instruments would answer the same ends. They are not merely substitutes for *cilia*. Cilia would simply effect the rapid renewal of the aërating element. *They* answer the manifold uses enumerated. Another variety of seta is intermixed with the former on the same flabellum. It consists of a sword-shaped process (fig. 8, *f*), less flexible than the former, from the edges of which secondary, acute, minutely-delicate points arise at an obtuse angle. They are designed only to act in one direction. They are situated chiefly on the margins of the flabellum (D). They exist on those placed vertically between the gills, as well as on that long whip-like flabellum which acts horizontally in the branchial cavity. They are less fitted to wipe the surface of the tubules than to catch at their edges when swiftly drawn over or between them. Thus they separate and momentarily hold apart the slender filaments of the branchiæ. Nearer to the root of each of these setæ, and only on one side, a second system of angular teeth occurs, which are turned backwards towards the root (Pl. XVII. fig. 9, C, E, D). They are thus capable of acting in a direction the reverse of the serrations placed on the extremity of the same seta. The *mop-like* variety of setæ does not exist on the flabella of those Crustacea the branchiæ of which are leafy or laminar.

Under the latter circumstances they would prove ineffective as cleansing utensils. They could perform no mechanical work on passing between smooth parallel laminæ. Between cylindrical filaments they act far otherwise. Nothing can surpass the efficiency of the contrivance. There exists such an evidently suitable relation between the structure and form not only of the flabella, but of their minutest hairs, and the shape and figure of the branchiæ in the same subject, that the incomparable ingenuity with which these little implements are adapted to the exact office to be discharged can only be appreciated by studying them in their connexions.

The *flabellum,* examined in its *general structure,* is a machinery no less remarkable. It consists of two horny parallel plates (Plate XVIII. fig. 9, *b, c*). Between these plates there travel with great regularity radiating currents of blood (*f*). The currents are separated by muscular fascicles (*e*), observing a similar disposition. The latter are levers of great power. Along the margins of the flabella the blood returns in large obvious channels. It is worthy of the special attention of the physiologist, that from these currents there proceed outwards at right angles minute streams traversing the axis of each microscopic seta (*a*). The fluid in these exists as a *single* column, sometimes as a flux and reflux stream moving in lacunæ (fig. 7, *a*). It does not advance and return along different conduits. In other words, the hollow axis of the seta is not divided by a longitudinal partition into two channels. It is a single tube. The blood in these parts moves in a flux and reflux manner. These little appendages, the structure of which is so accessible to the eye, express with great clearness the method in which constantly, *in all invertebrated animals,* the nutritive fluids reach the collateral recesses, the by-parts of the solids. In the Lobster, the biliary tubules (Pl. XVIII. fig. 10) resemble strikingly in structure the branchial. To establish further the manner in which, in the crustacean organism, the blood is related to the organized parts, it were at this place not inappropriate to allude incidentally to the minute anatomy of the liver-follicle of the Crustacea. It is a simple tube (fig. 10), having two coats embracing one another concentrically (*f*). Between these coats the blood flows in irregularly-bounded channels, forwards on one side, or half, and reversely on the other.

The hollow axis is filled by the secreted product (*c, g, h*). It is the commencement of the excretory duct. The epithelial cells of the outer coat are the same at every stage of the tubule (*a*). Those of the inner (*e*) begin to change in character as the extreme cæcal end of the tubule is approached. At first they are hexagonal and flat; by degrees they bulge; they become filled more and more with fluid, until at length they become spheroidal (*b*). They form a layer of several series deep. This end of the follicle, as supposed by Mr. Goodsir, is really the producing or secretive centre. The blood pervades irregular passages tunnelled between the spheroidal cells (*b*). The *fluid* elements of the blood pass from the blood-channels *into* the interior of the *modified* epithelial cells. From the latter it exudes into the *hollow axis* of the tubule (*c*). *This is the act of secretion*! The fixed cells impress upon the fluid by which they are traversed a *tendency to change,* a *disposition* to combine its elements anew. This change continues after the fluid escapes from the cells, *beyond the pale of the living* solids. The oil-cells (*c*) in the axis of the follicle are not organized cells, as represented by Dr. Leidy. They are mechanically-formed oil- and albumen-cells (*g*). The chemical change proceeds in the secreted product, *without* the *direct agency of cells*, as it flows from the distal to the proximal end of the tubule*. The *yellow colour* (*h, d*) is not developed until the product reaches nearly the middle of the tubule. The process of respiration can only be resolved to its last analysis by first determining with exactness the manner in which *other* vital nutritive acts are accomplished. The endosmose of gases requires that the partition should be thin (Pl. XVIII. fig. 5, *a, b*), the epithelial cells compressed and attenuated, and all unnecessary contents withdrawn; the act of *fluid* secretion demands the presence of the reverse conditions (fig. 10, *b*): such contrasted reasoning must prove directive to the thoughtful reader. Induction founded on contrasts serves often best to establish the *principia* of a science.

The branchiæ of the *Anomourous Crustacea* are arranged in the thoracic chamber in alternate series of fourteen in number. The chamber is open along the whole extent of its inferior boundary. To this circumstance is to be ascribed the *absence* in these Crustaceans of the flabella. They are not required. The influx and efflux of the water into the respiratory cavity are without such assistance unimpededly rapid. Propelling and guiding instruments would here prove a useless incumbrance. The gills in the Paguridæ are composed of laminæ. They are four-sided pyramids in shape. The respiratory leaflets are arranged however in a bipyramidal manner (Pl. XVII. fig. 7, B); that is, a wide channel (between *f* and *g*, fig. 7, B), coinciding with the length of the gill and with the primary blood-vessels, lies between the rows of leaflets which are built up on each side of the axis. Along this groove (fig. 9, *a*, fig. 7, *d*) rushes a current of water, descending along the gill on one side and ascending on the other. The ascent occurs on the inner side. The minutely-divided streams of water, which directly operate on the respiratory laminæ (or cylinders, as the case may be), connect these two main vertical currents by horizontally passing between the branchial leaves. If these laminæ were to become adherent through the absence of moisture, the respiratory process could no

* I have not attempted in the text, because it would be out of place, to compare the results of my own investigations on the structure of the liver-follicle of the Crustacea with those of Mr. Goodsir and Dr. Leidy. Such comparison must be made by the future student. I venture to think that neither the structure of the hepatic follicle nor the process of secretion has ever before been placed in so clear a light.

longer proceed. Thus the Crustacean dies rapidly in perfectly dry air; but if, in the branchial chamber, a sufficient proportion of humid vapour exist, the gaseous oxygen of the *air* (when the animal is out of water) is dissolved, and the breathing proceeds as efficiently as if the animal were still revelling in its native element. This mechanism explains the capacity with which many Crustacea are gifted, of living almost as well in air as in water. This apparent amphibious power does not prove that when in air they really breathe on the *atmospheric* plan, but that the oxygen of the *air* which is admitted into the branchial chamber is *fluidified by the moisture* which still remains in this cavity. The mechanism of the respiratory process, even under such circumstances, is *really aquatic in type*.

In ultimate structure the branchial laminæ in the gills of the Hermit Crab (Pl. XVII. fig. 7, B), conform exactly with those of the Brachyurous orders, subsequently to be explained. The coats of the axial branchial vessel in the Hermit Crab are smooth, and destitute of those hooks which are distributed so systematically over those of the common edible Crab (Pl. XVIII. fig. 6). The hooks are not required because there are no flabella. The setæ (Pl. XVII. fig. 7, M) which depend from the *roof* of the branchial cavity of the former present the *mop-like* character of those already described in the Lobster.

In the *Brachyurous* orders, exemplified by the vulgar edible Crab, the gills are constructed on the leafy or laminar principle (Pl. XVII. fig. 9, A). They stand vertically in the containing chamber. The leaves on each gill are arranged in two series (*a*), one on either side of the longitudinal blood-channels. The shape of the ultimate leaves differs in different species. In some they are semilunar; in others they are reniform, in others pointed, &c.; in all they leave deep grooves for the free play of the branchial current from the root to the apex of the gill, and from the apex to the root on the other side. The streams passing horizontally between the leaflets connect the two main longitudinal currents. Thus the water-currents on the outside of the branchiæ observe the same distribution and division as the blood in the interior. The structure of the branchial laminæ admits of resolution to the very last elements of organic structure. They are inconceivably slender and delicate. The most cautious attempt to inject the gills converts the leaf into a bag, the lamina into a sac, so delicately are the plates held together; but though thus attenuated in the extremest degree, each lamina consists of two opposed plates.

These plates are composed exclusively of a single layer of epithelial cells, hexagonal in outline, and adjusted edge to edge. Under the highest power of the microscope they exhibit minute